Technology-to-Market (T2M) for LENR

Sam Wurzel, Technology-to-Market Advisor, ARPA-E

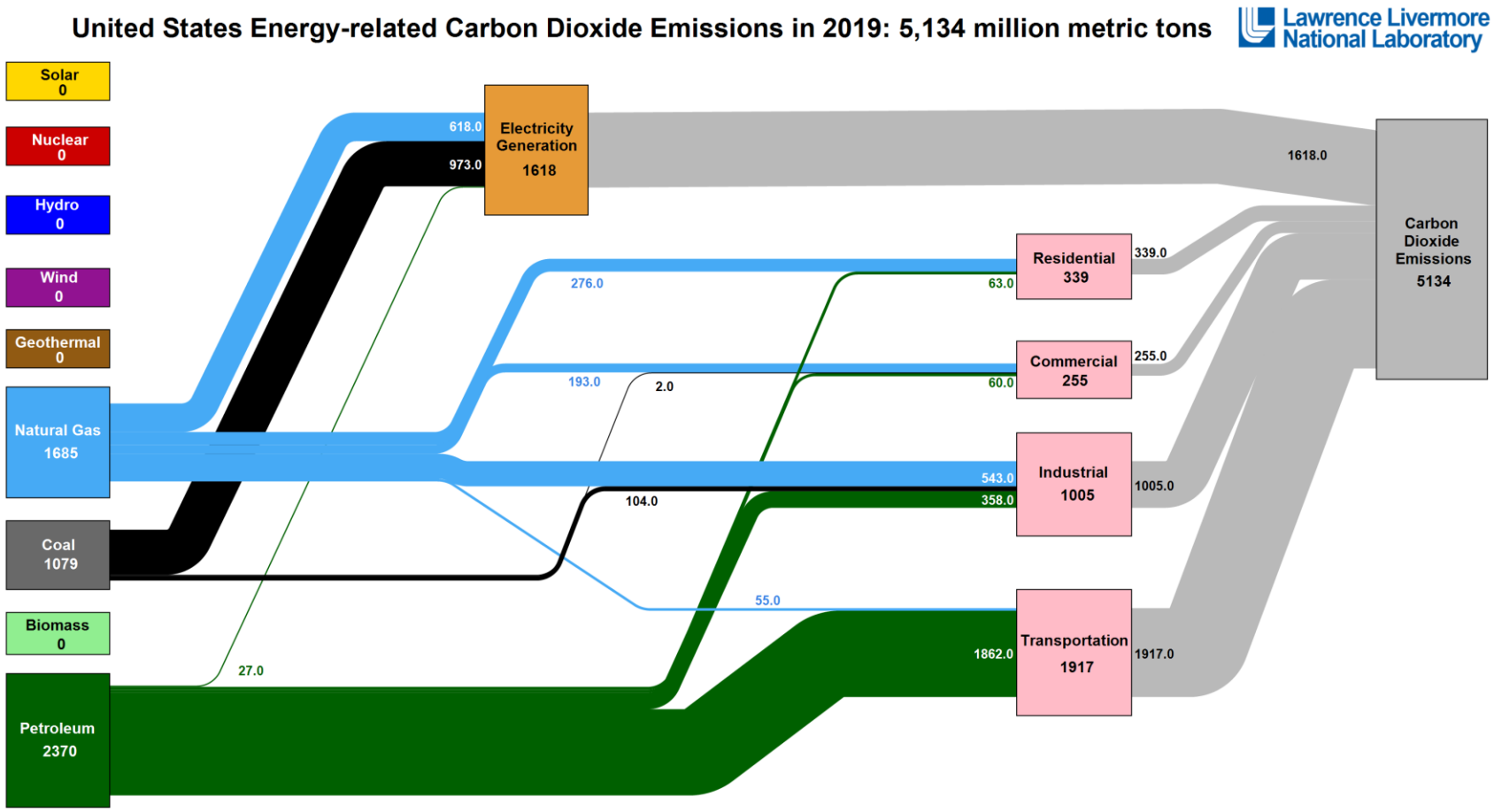
ARPA-E LENR workshop (virtual)
October 22nd, 2021

Outline

- Framing of T2M at ARPA-E
- Getting to a development path for LENR T2M
- Physics-based metrics
- Potential markets and minimum viable products
- Techno-economic metrics

What problem are we trying to solve?

Gigaton scale reductions in CO2 emissions…

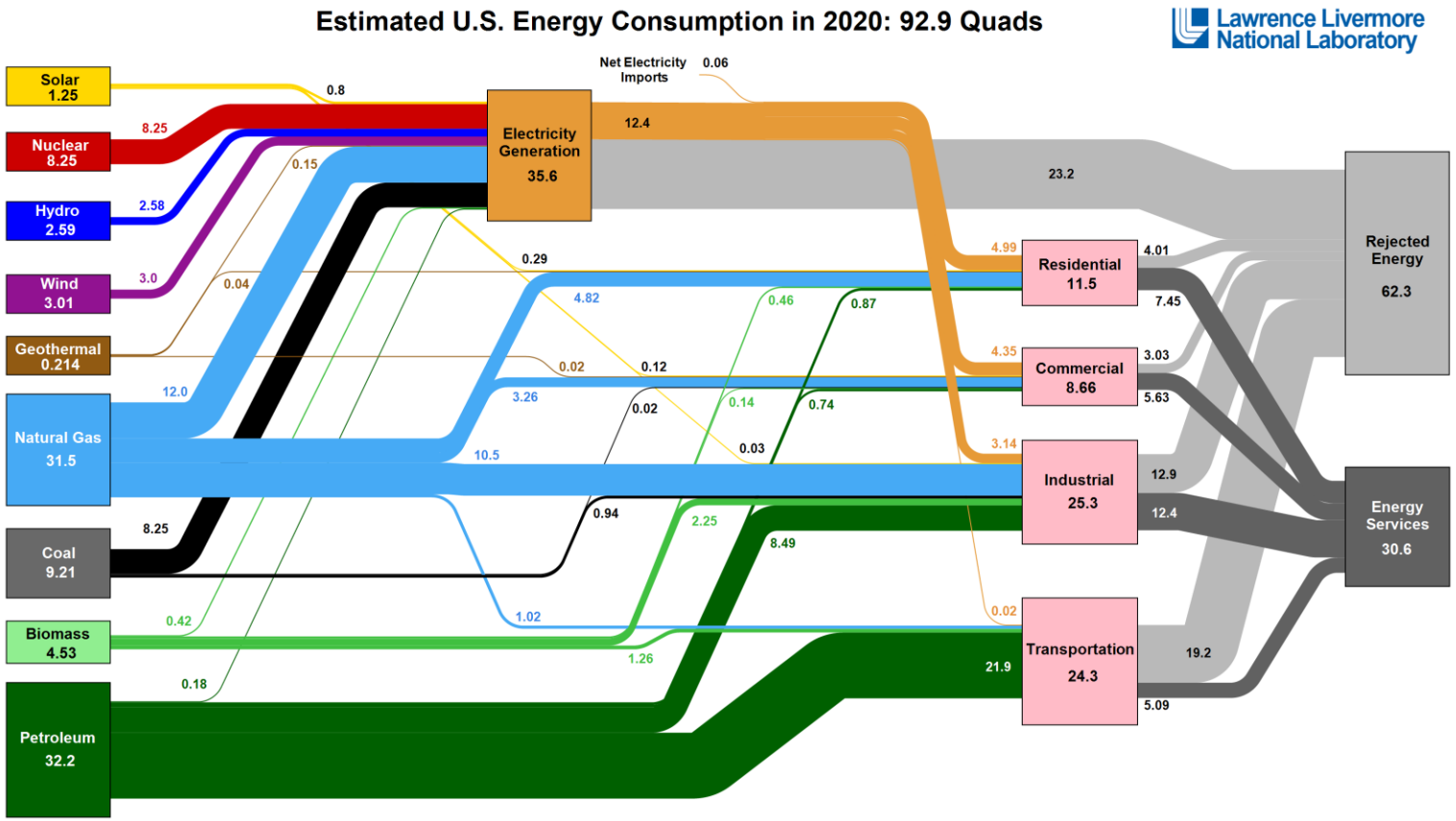


Source: LLNL July, 2021. Data is based on DOE/EIA MER (2019). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant heat rate. The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential sector, 65% for the commercial sector, 21% for the transportation sector and 49% for the industrial sector, which was updated in 2017 to reflect DOE's analysis of manufacturing. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

arpa·e
CHANGING WHAT'S POSSIBLE

What problem are we trying to solve?

…require quad level energy impact



Source: LLNL March, 2021. Data is based on DOE/EIA MER (2020). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant heat rate. The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential sector, 65% for the commercial sector, 21% for the transportation sector and 49% for the industrial sector, which was updated in 2017 to reflect DOE's analysis of manufacturing. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

arpa·e
CHANGING WHAT'S POSSIBLE

Technology to Market at ARPA-E: If it works, will it matter?

SCOPE

Market insights → techno-economic metrics

MANAGE

Technical and T2M milestones

ADVISE

Dedicated T2M Advisor

PARTNERSHIPS

Connect teams with investors and other commercial stakeholders

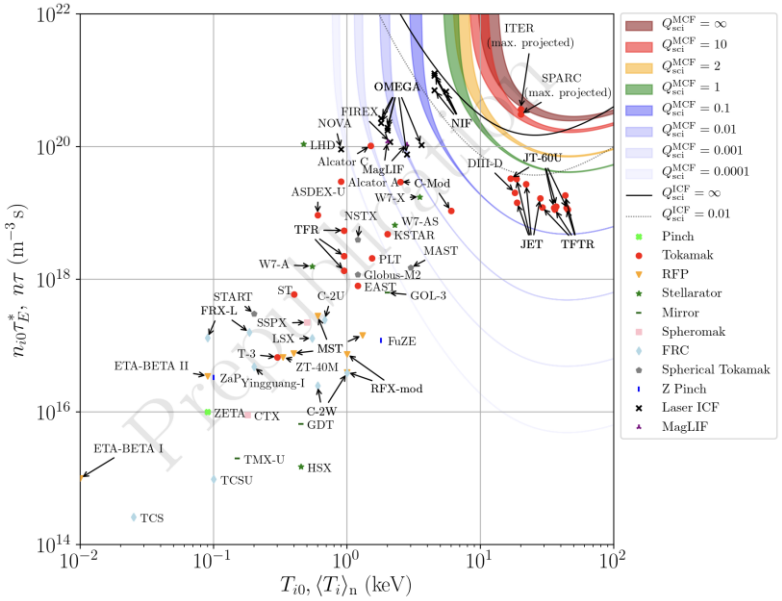
arpa·e
CHANGING WHAT'S POSSIBLE

Getting to a development path for LENR T2M requires upfront work

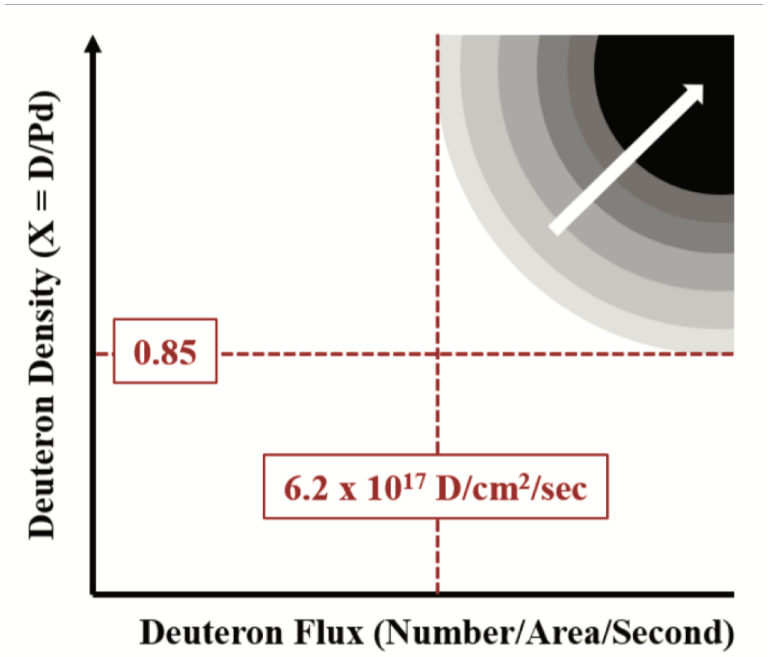
- Identification of key physics and technical metrics
- Market identification consistent with physics and technical metrics
- Identification of minimum viable products (MVP)
- Identification of required techno-economic metrics

Physics metrics: analogy with thermonuclear fusion energy?

- Key physical metrics for conventional fusion were identified by Lawson in 1955 by analyzing energy balance of a fusion plasma
- Is there a “Lawson criterion” for LENR?
- What are LENR’s physics metrics for energy gain? Or other physics based metrics?



Wurzel, Hsu 2021
https://arxiv.org/abs/2105.10954



Nagel 2021
http://www.infinite-energy.com/iemagazine/issue157/NagelIE157.pdf

Physics metrics: analogy with Drake equation?

- Description of excess power when some factors are unknown
- Tangentially related to Drake equation where outcome depends on accuracy of probabilities

The Drake equation is:

$$N = R_* \cdot f_\mathrm{p} \cdot n_\mathrm{e} \cdot f_\mathrm{l} \cdot f_\mathrm{i} \cdot f_\mathrm{c} \cdot L$$

where:

N = the number of civilizations in our galaxy with which communication might be possible (i.e. which are on our current past light cone);

and

R_* = the average rate of star formation in our Galaxy

f_p = the fraction of those stars that have planets

n_e = the average number of planets that can potentially support life per star that has planets

f_l = the fraction of planets that could support life that actually develop life at some point

f_i = the fraction of planets with life that actually go on to develop intelligent life (civilizations)

f_c = the fraction of civilizations that develop a technology that releases detectable signs of their existence into space

L = the length of time for which such civilizations release detectable signals into space[5][6]

https://en.wikipedia.org/wiki/Drake_equation

$$Power = K * X * A * C * e^{-B/RT}$$

K = Constant of appropriate units
X = Related to isotope fraction of H vs D
A = Number of NAE (nuclear active environments)
C = Concentration of hydrogen isotopes around NAE
B = Diffusivity of Hydrogen in material
T = *Temperature*
R = *Constant of appropriate units*

Storms, "The Explanation of Low Energy Nuclear Reaction: An Examination of the Relationship Between Observation and Explanation", 2014

Potential first LENR markets

- With clear physics metrics, we can investigate markets with significant global total addressable markets (TAM)
- Residential Hot water heating (TAM $27B)
- HVAC (TAM $127 B)
- Industrial boilers (TAM $14B)
- Transportation
  - Automobiles (TAM $2.7T)
  - Maritime propulsion (TAM $33B)

Potential first LENR minimum viable products

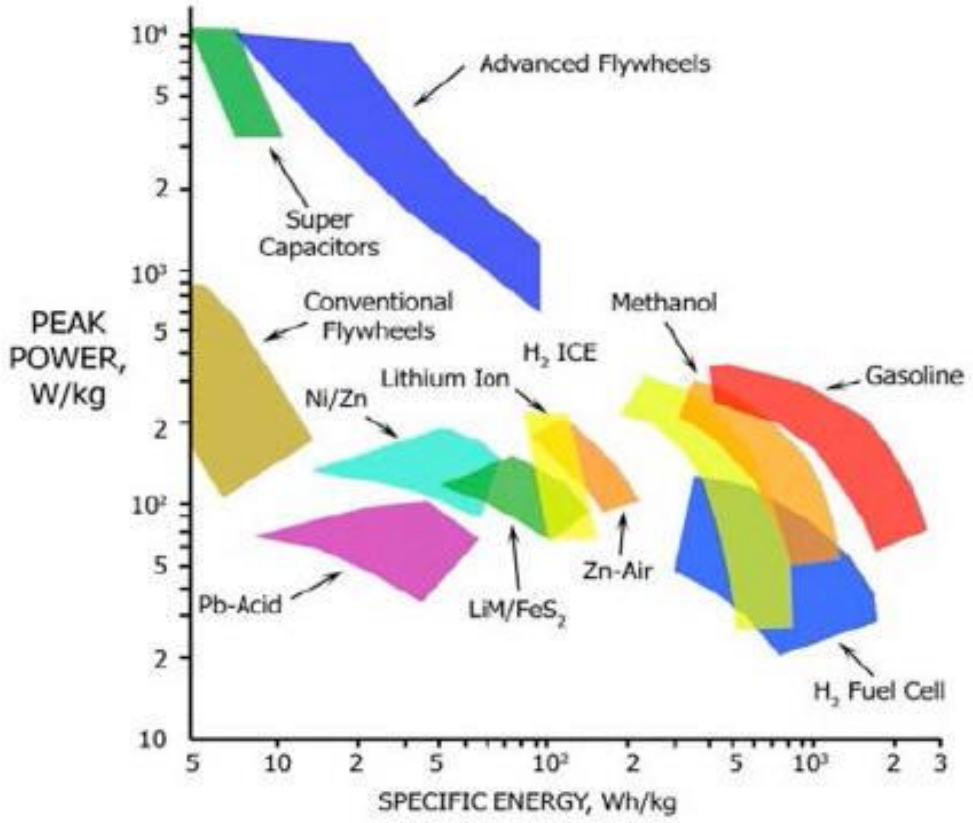
- Hot water heaters, HVAC, industrial boilers
  - kWs of heating power
  - Low duty cycle
  - 1m physical dimensions
  - Tens to thousands of kgs

- Transportation
  - Trickle charging of EV batteries at hundreds of Watts or kW level
  - High duty cycle
  - <1m to 10m physical dimensions
  - Hundreds or thousands of kgs

arpa·e
CHANGING WHAT'S POSSIBLE

Techno-economic drivers and metrics for LENR

- Specific power: Watts/kg
- Capital costs: $/Watt
- Energy density: Joules/kg
- Operational costs: $/Joule
- Unit Lifetime
- RAMI (Reliability, Accessibility, Maintainability, Inspectability) considerations



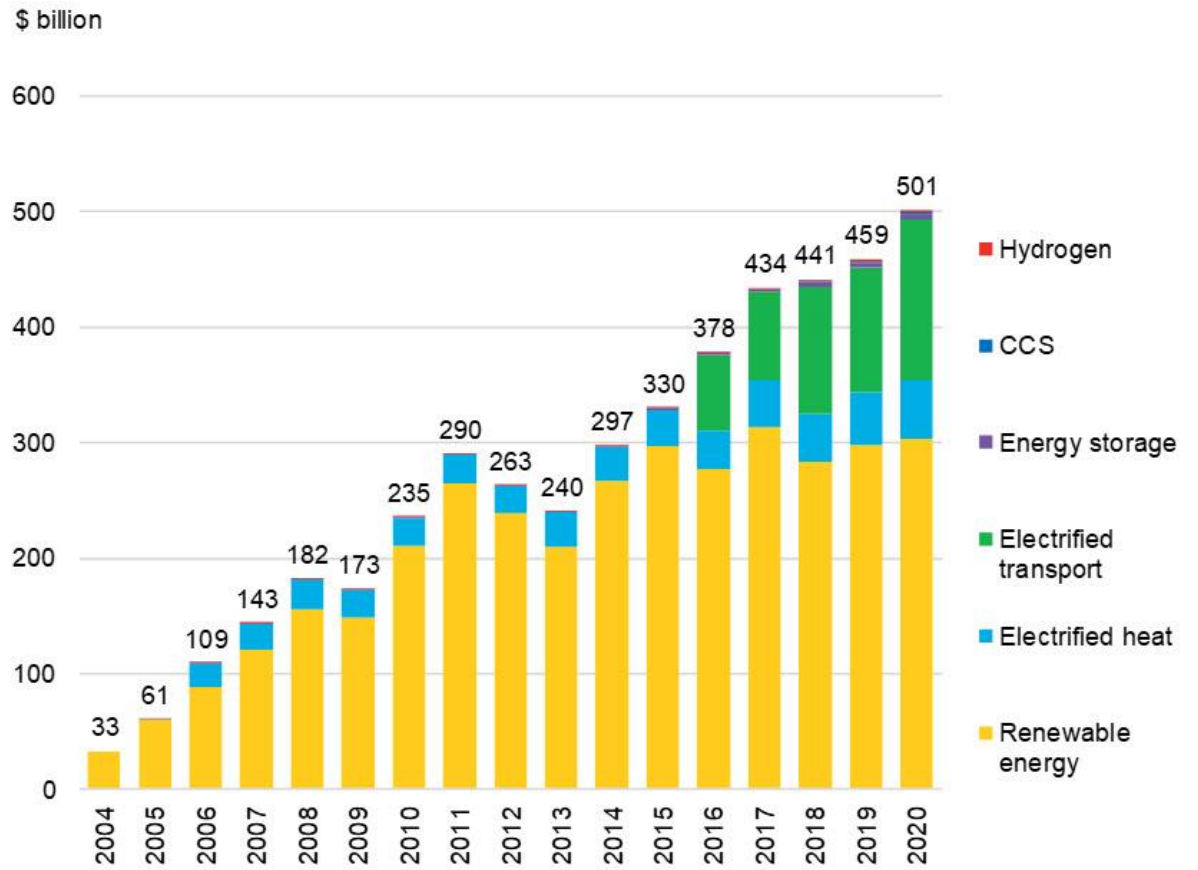
Ahmed F. Ghoniem, Needs, resources and climate change: Clean and efficient conversion technologies, Progress in Energy and Combustion Science, Volume 37, Issue 1, 2011

Investment landscape for non-fossil energy technologies

- Capital is available for teams that demonstrate
  - Physics certainty
  - Performance of physics and techno-economic metrics
  - Working prototypes

- A reference experiment would unlock significantly more capital

Figure 1: Global energy transition investment, 2004-2020



Source: BloombergNEF. Note: electrified heat figures begin in 2006; electrified transport in 2016; hydrogen and CCS in 2018.

Other T2M Considerations

- Intellectual property
- Export control
- Public perception, social acceptance
- Supply chain risks

U.S. DEPARTMENT OF ENERGY

https://arpa-e.energy.gov

Questions for discussion

- What are the right metrics to consider?
- What level of demonstration could reasonably be achieved in a focused ARPA-E program?
- What level of demonstration is required to sprint towards a product?
  - What level of reliability?
  - What level of power?
  - What level of understanding of underlying physics?
- What does a minimum viable product (MVP) look like?

Backup

RFI Response, Dana Seccombe